

## CLAIMS

1. A pollution reduction process, comprising substantially removing in a sequential series of processes a plurality of pollutants including nitrogen oxides, sulfur dioxide, dioxins, furans, volatile trace metals in ash, including at least one of arsenic, lead, and mercury, wherein each of the sequential series of process removes one or more of the pollutants individually and in combination further reduce the plurality of pollutants without impairing wall materials in furnace or boiler.

2. The method in accordance with claim 1, wherein the pollutant reduction processes include two groups, wherein a first of the two groups takes place in a primary combustion zone where fuel is injected and fired with combustion air, followed by a second of the two groups which take place in a post combustion zone between an exit of combustion gases from the primary combustion zone and a duct immediately upstream of a particle filter or electrostatic precipitator.

3. A method in accordance with claim 2, wherein the first group process reduces the nitrogen oxides by operating a slagging, air-cooled, cyclone combustor or the primary combustion zone under fuel rich conditions.

4. A method in accordance with claim 2, wherein the first group process reduces sulfur dioxide formed by combustion of the fuel by reaction in a gas phase in a slagging

cyclone combustor with co-injected limestone or externally calcined limestone particles in a size range between about 10 and 74 microns, with at least two-thirds to three-quarters the reacted calcium-sulfur particles and un-reacted calcium oxide particles impacting and dissolving in a liquid slag layer lining a combustor wall.

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5. A method in accordance with claim 4, wherein ash content in the fuel is insufficient to achieve a slag flow residence time in the combustor of under 3 minutes, in which case more than 50% by weight of ash in a char or high ash coal washing residue is co-injected with coal and limestone in a quantity sufficient to achieve slag mass flow rates on the combustor wall that result in slag residence times in the combustor of less than about 3 minutes.

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6. A method in accordance with claim 4, wherein fine sulfur powder of particle size of approximately less than 75 microns is mixed with sawdust whose function is to act as a carrier of the fine sulfur with the sulfur sawdust mixture being injected in ports adjacent to that of a sulfur content coal having less than approximately 1% at a mass flow rate of the sulfur-sawdust mixture substantially equal to a 1% or higher sulfur bearing coal for optimizing a sulfur capture process in a slagging combustor by separating the sulfur capture process from a sulfur retention process in a liquid slag layer on the combustor wall, with optimization being implemented with co-injection of a high ash material, such as rice husk char that has less than 1% sulfur.

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7. A method in accordance with claim 2, wherein for a first group process the volatile trace metals in coal or fuel including at least one of arsenic and mercury, is gettered by porous carbon activated char that is injected through ports adjacent to fuel injection ports, with the char being in a particle size range between about 10 and 74  
5 microns, and with the reacted char particles impacted and being removed with the slag drained from the combustor.

8. A method in accordance with claim 2, wherein for a first group process the volatile trace metals in coal or the fuel including at least one of arsenic and mercury is  
10 gettered by porous limestone that is injected through ports adjacent to fuel injection ports, with the limestone being in a particle size range between about 10 and 74 microns.

9. A method in accordance with claim 5, wherein liquid slag is quenched in a water filled tank as the liquid slag drains from a floor at a downstream end of the slagging  
15 cyclone combustor.

10. A method in accordance with claim 2, wherein for a first group process the dioxins and furans are reduced inside a slagging, air-cooled, cyclone combustor by reaction with limestone particles that are injected and removed in slag by reaction in a  
20 gas phase in the slagging, air-cooled cyclone combustor with co-injected limestone or externally calcined limestone particles in a size range between about 10 and 74 microns, with at least two-thirds to three-quarters of reacted calciumchlorine particles and un-

reacted calcium oxide particles impacting and dissolving in a liquid slag layer lining a combustor wall.

11. A method in accordance with claim 10, wherein plastic pellets of approximately  
5 1 millimeter in diameter or less, are injected through ports adjacent to the fuel ports in order to provide a uniformly fed source of chlorine to determine an impact of uniform feeding on dioxin/furan formation and capture in the combustor.

12. A method in accordance with claim 2, wherein for a first group process the  
10 dioxins and furans are reduced in mass burn municipal waste incinerators that utilize a traveling grate for combustion, in which gas burners, using either natural gas or pyrolysis gas derived from municipal waste are used to achieve a uniform temperature in a visible flame region of the furnace by means of individual gas burners that are fired, as required, to assure a uniform visible flame or a uniform flame as determined from thermocouple  
15 measurements, with the uniform flame being in a gas temperature range of about 1700°F to 2200°F into which aqueous droplets of varying size from about 100 to 1000 microns and containing dispersed limestone in a range of about 10 to 74 micron are injected in a flat fan spray perpendicular to an upward gas flow direction with a predetermined number of injectors sufficient to intercept an entire upward gas flow, and with a  
20 limestone mass flow rate to neutralize the sulfur dioxide and chlorine gas compounds to prevent acid formation in cooler exhaust ducts, and at mass flow rates to reduce a concentration of the dioxins and furans formed in the high temperature gas.

13. A method in accordance with claim 2, wherein the nitrogen oxides are reduced in one of the second group processes including introducing additional fuel, including one of pulverized coal, oil and gas, in a quantity to convert fuel lean combustion gases leaving a primary combustion zone to between about 90% to 99% of unity stoichiometry, with final combustion air introduced downstream of a fuel rich zone to reconvert the combustion gases to at least 110% excess air stoichiometry, and with the gas temperature in the fuel rich zone in a temperature range from about 1700°F to 2600°F.

14. A method in accordance with claim 13, wherein the nitrogen oxides are eliminated in a fuel rich post combustion zone downstream of the primary combustion zone by injecting into the fuel rich zone a flat spray of aqueous droplets perpendicular to a gas flow direction, or in parallel and opposed to the gas flow direction, with the aqueous droplets containing dissolved urea or ammonia in concentration equal to at least a mol ratio of unity to the nitrogen oxides, and with the aqueous droplets having a size distribution ranging from about 10 microns to 1000 microns.

15. A method in accordance with claim 14, further comprising injecting an aqueous solution to reduce the nitrogen oxides which contains dispersed lime particles of mean size of about 10 micron in concentration of less than 25% by mass of water and a mass flow rate sufficient to achieve a mol ratio of up to 3 to the sulfur dioxide concentration to

reduce the sulfur dioxide concentration and a mol ratio in excess of unity to a chlorine concentration to reduce the chlorine concentration in the combustion gases.

5        16: A method in accordance with claim 2 wherein the aqueous solution utilized to reduce the nitrogen oxides in the group two process also contains dispersed lime particles of mean size of about 10 microns in concentration of less than 25% by mass of the water and a mass flow rate sufficient to achieve a mol ratio of up to 3 to the sulfur dioxide concentration in order to reduce it and a mol ratio of unity to the chlorine concentration in  
10        order to reduce it in the combustion gases in the temperature region of 1700°F to 2600°F.

17.        A method in accordance with claim 2, wherein the second group process is implemented in exhaust ducts of the furnace or boiler to remove any residual dioxins and furans by injection of water droplets of varying size between about 10 microns and 1000  
15        microns into a gas stream downstream of economizers or heat changers at initial temperatures between about 350°F and 700°F in sufficient mass flow rates to cool the gases to about 250°F, with injectors producing either a flat spray perpendicular to the gas flow direction or a conical spray co-axial and opposed to the gas flow direction.

20        18.        A method in accordance with claim 2, wherein for one of the group two process the lime particles are mixed with and dispersed in the aqueous solution prior to injection into the duct for neutralizing any residual acid compounds of sulfur, chlorine or nitrogen,

if analysis of gas samples taken upstream of the injection in a gas temperature range of about 350°F to 700°F show a presence of the gas species.

19. A method in accordance with claim 2, wherein one of the second group process is  
5 implemented to remove any residual dioxins, furans, and mercury remaining in a gas stream by injection of aqueous droplets of varying size between about 10 microns and 1000 microns that contain dispersed activated carbon particles and at least one of a surfactant and stabilizer, if needed, to prevent agglomeration of the activated carbon particles, and the aqueous droplets being injected either in a flat fan spray pattern  
10 perpendicular to the gas stream, or in a conical spray patterns coaxial with the gas stream and facing in an upstream direction.

20. A method in accordance with claim 12, wherein all the predetermined number of injectors utilize a same flat fan spray of conical spray design to have them compatible  
15 with a temperature range of insertion for a gas stream being treated.

21. A method in accordance with claim 2, wherein any solid particles remaining in the gas stream downstream of the two group process are removed either by a fabric filter or electrostatic precipitator.

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22. A method in accordance with claim 21, wherein an induced draft fan is used to provide sufficient draft to force the gas stream out of a stack of the boiler or furnace into atmosphere.

5 23. A method in accordance with claim 2, wherein the first group process includes kinetic vitrification which includes a series of non-equilibrium processes that occur within the primary combustion zone into which pulverized coal is co-fired with solid particle reagents that capture part of gaseous sulfur compounds and vaporized trace metals.

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24. A method in accordance with claim 23, wherein reacted particles and solid and liquefied ash particles in coal that contain trapped trace metals impact, melt in a liquid slag layer that lines an air-cooled combustor wall.

15 25. A method in accordance with claim 24, further comprising air-cooling the combustor wall to allow rapid drainage of the liquid slag layer into a water filled quench tank, before the reacted sulfur and trapped trace metals can re-evolve into the gas stream, wherein the quenched slag is chemically inert.

20 26. A method according to claim 25, further comprising simultaneously partially reducing the nitrogen oxides by operating the combustor in a staged combustion mode in



which fuel rich conditions are maintained in the combustor and additional air is introduced in a post-combustion zone for final burnup of residual gaseous fuel.

27. A method according to claim 2, wherein the second group is implemented in a high  
5 temperature post-combustion zone, wherein remaining sulfur and nitrogen oxides and chlorine are removed from the gas stream by reagent injection using an injector and by re-burning the combustion gases.

28. A method in accordance with claim 27, further comprising water spray cooling,  
10 using injectors, in exhaust ducting to reduce concentrations of the dioxins and furans and downstream in the exhaust ducting to disperse activated carbon particles in order to remove any remaining mercury and dioxins and furans.

29. A pollution reduction process, comprising:

15 a first group of processes taking place in a primary combustion zone where fuel, coal or other solid fuels are injected and fired with combustion air; and

a second group of process taking place in a post combustion zone between an exit of combustion gases from the primary combustion zone and a duct upstream of a particle filter,

20 wherein the first and second group processes, in combination, are provided in sequential order and substantially reduce a plurality of pollutants including nitrogen

oxides, sulfur dioxides, dioxins, furans, volatile trace metals in ash, including at least one of arsenic, lead, and mercury.

30. A method according to claim 29, wherein the first group of processes include:

5 staged combustion, in which a stoichiometry in the combustion chamber is fuel rich, followed by excess air combustion at a combustor outlet to reduce the nitrogen oxides;

injection of lime or limestone particles in dry powder or liquid slurry form near coal injection ports to reduce the sulfur dioxides, wherein the lime or limestone particles are  
10 calcined by combustion gas to calcium oxide that reacts with gaseous sulfur molecules to form a solid calcium-sulfur particles;

kinetic vitrification of the volatile trace metals; and

ash vitrification such that produced slag is quenched in a water-filled tank and converted into a chemically inert, vitrified slag.

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31. A method in accordance with claim 30, wherein the solid calcium-sulfur particles and solid and liquid droplets of ash that are released during coal combustion and that are greater than about 10 microns in diameter impact and dissolve in the slag that lines an inner wall of a slagging combustor.

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32. A method in accordance with claim 31, further comprising air-cooling to control a slag layer temperature and viscosity so that the slag is drained into the water filled

quench tank to prevent re-evolution of sulfur trapped in the slag, wherein the slag layer flow rate is further controlled by the lime or limestone particles injected at rates beyond requirements for sulfur control, the lime or limestone particles further reducing high temperature formation of the dioxins and furans that result from reactions with chlorine in the fuel.

33. A method in accordance with claim 29, wherein the second group process includes:

reburning in post-combustion gases between 1700°F and 2600°F to convert fuel lean combustion gases to a fuel rich condition, which reduces the nitrogen oxides;

injecting in said 1700°F to 2600°F gas temperature zone aqueous droplets containing urea or ammonia and lime or limestone particles dispersed in the aqueous droplets taking place in one of a post-combustion fuel rich zone and fuel rich gases exiting from a primary combustion zone to reduce nitrogen oxides, sulfur oxides and chlorine and chlorine compounds;

one of (i) injecting air downstream of a reagent injection zone or downstream of the reburn zone to complete combustion of the fuel rich gases and (ii) mixing treated fuel rich gas with untreated combustion gases that have excess air and to complete the unburned fuel combustion; and

to remove substantially fur dioxide and chlorine and nitrogen dioxides that remained in the gases exiting the primary combustion chamber.

34. A method in accordance with claim 21, wherein a heat exchanger is used to reheat the combustion gas in order provide sufficient buoyancy to force the gas stream out of the boiler or furnace stack into atmosphere.